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Reducing Sodium in Processed Meats Using Traditionally Brewed Soy Sauce and Fermented Flavor Enhancer

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Abstract: As interest continues in sodium reduction technologies, there is a need to understand the changes in physiochemical and sensory characteristics of reduced sodium food products. Previous research has shown that traditionally brewed soy sauce (SS) and fermented flavor enhancer (NFE) offer efficacy as viable sodium reduction ingredients. However, their ability to provide similar results in other meat products with different requirements (e.g., flavor, functionality, etc.) for salt is not well understood. In this study, bacon, beef jerky, summer sausage, and boneless ham treatments were generated with sodium reductions of 30 and 50% by including either SS or NFE alone and in combination with potassium chloride (KCl). Sensory and quality measurements, including salty taste, and product qualities such as color, purge, and texture profiles were evaluated. No differences ($P > 0.05$) were observed for overall liking of bacon at 30 (SS and NFE) and 50% (SS) reductions containing KCl, and for overall liking of beef jerky (NFE) and boneless ham (SS) at 30% reductions utilizing either SS or NFE as a salt reduction tool. Further, saltiness liking scores showed no change ($P > 0.05$) at 30% reductions in bacon, beef jerky and boneless ham, while a decreased liking ($P < 0.05$) were observed in summer sausage products containing SS and NFE. These results suggest the use of SS and NFE can increase perceived salty taste without increasing the sodium content of multiple products investigated. These results indicated that SS and NFE are suitable ingredients to utilize in processed meat products to reduce sodium content, while each product has unique and variable responses in sensory attributes that must be considered.

Keywords: fermented flavor enhancer, processed meats, sodium reduction, traditionally brewed soy sauce
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Introduction

Sodium chloride (NaCl) is an essential ingredient for processed meat products providing consumer expected saltiness and existing meat flavor enhancement (Weiss et al., 2010), allowing successful manufacturing due to the effect NaCl has on the solubility of the myofibrillar meat proteins actin and myosin impacting binding, texture, and water holding capacity (Aberle et al., 2001), and serving as an important antimicrobial by helping control of a range of pathogenic and nonpathogenic microorganisms (Doyle and Glass, 2010).

Regardless of these well understood and scientifically important NaCl functions, there continues to be great interest from consumers and efforts from human health organizations to reduce the overall sodium intake in the human diet (Webster et al., 2011). Thiel et al. (1986) reported that reductions of 50% or more significantly decreased saltines perception, cook yield, and texture values in ham. Aaslyng et al. (2014) found that reducing sodium in bacon and salami by 50% had a negative effect on sensory, shelf life, and microbial properties.

It is well understood the chloride ion of the NaCl molecule is responsible for primary meat process-

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ing functions (e.g., myofibrillar protein solublization, changes in product texture, and impact on water holding capacity) while the sodium ion is largely responsible for flavor contributions (Wismer-Pedersen, 1987). Simply reducing the NaCl concentration of a product can have detrimental effects if concentration thresholds important for NaCl functionality are not attained. A common approach to sodium reduction in the meat and poultry industries over the past couple decades has been to replace a portion of NaCl with another chloride containing salt molecule. This method allows for the perseveration of important chloride function to be maintained. But clear limitations, namely off flavors, identified by Gou et al. (1996), created by the non-chloride ion of the molecule are apparent if off-flavor producing concentration thresholds are reached thus creating clear challenges from this approach. The feasibility of replacing some or all NaCl with other chloride containing salts has been thoroughly investigated and studies have included a variety of food-grade molecules such as potassium chloride (KCl), magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$: Frye et al., 1986; Gou et al., 1996).

Another alternative approach to sodium reduction has been to incorporate salt potentiating ingredients into sodium reduction systems. The addition of ingredients containing salty-potentiating compounds such as umami, for example, has been shown to not only enhance the salty taste but also other tastes and flavor notes of food products (Fuke and Ueda 1996; Keast and Breslin, 2002). Traditionally brewed soy sauce (SS; comprised of water, NaCl, soybeans, and wheat) and fermented flavor enhancer (NFE; comparable to SS but manufactured to possess less soy flavor, a lighter color, and umami flavor amplification) are 2 ingredients of particular interest for this research as they both contain high levels of umami substances generated through a fermentation process from contributing amino acids and peptides (Fukushima, 2004; Kremer et al., 2009; Goh et al., 2011; Jiménez-Maroto et al., 2013; Kremer et al., 2013a; Kremer et al., 2013b; Shimojo et al., 2014). Recent research (McGough, 2011; McGough et al., 2012a; McGough et al., 2012b) has shown the use of SS and NFE can be successfully implemented into a sodium reduction system for frankfurters where sodium reduction of 20% singly or 35% in combination with KCl were achieved with no significant ($P > 0.05$) impact on quality or consumer acceptance. However, the results of this research were limited in scope since these experiments only investigated efficacy for frankfurters and were not able to ascertain any sodium reduction feasibility in other processed meats possessing different requirements for NaCl inclusion.

In previously completed and closely related work, Shazer (2014) investigated 25, 50, and 75% replacement concentrations of NaCl from formulation flake salt with NaCl from either SS or NFE in bacon, beef jerky, summer sausage, and boneless ham. Results of this NaCl replacement study identified treatments for further evaluation containing SS and NFE replacement for bacon (50 or 75% SS/NFE), beef jerky (50 or 75% SS/NFE), boneless ham (25% SS or 50% NFE), and summer sausage (50% SS/NFE).

Therefore, the objectives of this present study were: 1) to investigate the ability to reduce sodium with SS or NFE inclusion in bacon, beef jerky, summer sausage, and boneless ham and 2) to assess the potential of further sodium reductions by including KCl with SS and NFE.

Materials and Methods

Experimental treatments

Treatments for all products investigated in this study included the following sodium reduction formulations: 100FS: no sodium reduction (100% flake salt); 30SS: 30% NaCl reduction using SS for attaining a 30% decrease in sodium, 50SS/KCl: 50% NaCl reduction using SS and KCl for attaining a 50% decrease in sodium, 30NFE: 30% NaCl reduction using NFE for attaining a 30% decrease in sodium and, 50NFE/KCl: 50% NaCl reduction using NFE and KCl for attaining a 50% decrease in sodium. Flake salt was only included in the TRT formulations (boneless ham 30SS, 50SS/KCL, and 30NFE; and summer sausage 30 SS and 30NFE) if the SS or NFE optimum replacement level previously identified for any of the 4 products was not 75%. All SS, NFE, KCl, and flake salt concentrations added in this experiment were calculated from the respective 100FS salt level established for each product type. Treatment combinations are outlined in Table 1.

Soy sauce and fermented flavor enhancer preparation

Traditionally brewed soy sauce (Kikkoman product codes 00050 and 00070; Kikkoman Foods Inc., Walworth, WI) contained the following ingredients: water, salt, wheat, and soybeans. Previous research (McGough, 2011) showed that a residual protease was present in SS which can break down meat proteins and disrupt meat emulsions and affect the quality of meat products. Therefore, in an effort to mitigate any potential effects, the SS was treated by cooking in a water

Table 1. Salt levels and sources of NaCl in bacon, beef jerky, boneless ham, and summer sausage containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Treatments[1]				
Products	100FS	30SS	50SS/KCl	30NFE	50NFE/KCl
Bacon					
Formulation Salt Level, %[2]	1.6	1.12	0.8	1.12	0.8
Salt from SS, %[3]	0	1.12	0.8	0	0
Salt from NFE, %[4]	0	0	0	1.12	0.8
Flake Salt Added, %[5]	1.6	0	0	0	0
Potassium Chloride, %	0	0	0.8	0	0.8
Water Added, %[6]	9.5	3.59	4.97	2.65	4.30
Beef Jerky					
Formulation Salt Level, %[2]	3.0	2.1	1.5	2.1	1.5
Salt from SS, %[3]	0	2.1	1.5	0	0
Salt from NFE, %[4]	0	0	0	2.1	1.5
Flake Salt Added, %[5]	3.0	0	0	0	0
Potassium Chloride, %	0	0	1.5	0	1.5
Water Added, %[6]	12.66	3.12	5.35	1.59	4.26
Boneless Ham					
Formulation Salt Level, %[2]	2.25	1.58	1.13	1.58	1.13
Salt from SS, %[3]	0	0.57	0.57	0	0
Salt from NFE, %[4]	0	0	0	1.13	1.13
Flake Salt Added, %[5]	2.25	1.01	0.57	0.45	0
Potassium Chloride, %	0	0	1.13	0	1.13
Water Added, %[6]	13.08	10.56	10.51	7.22	7.18
Summer Sausage					
Formulation Salt Level, %[2]	2.5	1.75	1.25	1.75	1.25
Salt from SS, %[3]	0	1.25	1.25	0	0
Salt from NFE, %[4]	0	0	0	1.25	1.25
Flake Salt Added, %[5]	2.5	0.5	0	0.5	0
Potassium Chloride, %	0	0	1.25	0	1.25
Water Added, %[6]	12.41	5.71	5.68	4.60	4.57

[1]Treatments SS and NFE levels varied for each product based on optimum levels of SS and NFE determined in previous study: 100FS = no sodium reduction; 30SS = 30% sodium reduction with SS; 50SS/KCl = 50% sodium reduction with SS and 50% KCl; 30NFE = 30% sodium reduction with NFE; 50NFE/KCl = 50% sodium reduction with NFE and 50% KCl.

[2]Formulation salt level includes salt from flake salt and salt from cure (93.75% salt) and shows overall reductions for each treatment.

[3]SS = Soy sauce, analyzed for salt content (13.7% NaCl w/w).

[4]NFE = Fermented flavor enhancer, analyzed for salt content (12.1% NaCl w/w).

[5]Flake salt added was amount of flake salt used in formulation.

[6]Water added (formulation basis) varied to account for added water through SS or NFE.

bath in a sealed vessel at 75°C for 7 h then cooled and stored at 4°C until needed. The NFE (Kikkoman product code 00619; Kikkoman Foods, Inc., Walworth, WI) contains the same ingredients as SS but its manufacturing processes included a protease inactivation procedure; therefore, no protease inactivation prior to our use was necessary. The SS used for all studies included 13.7% salt while NFE contained 12.1% salt.

Product manufacture

All products in this study were manufactured at the University of Wisconsin Meat Science and Muscle Biology Laboratory (Madison, WI) using good manufacturing practices and typical commercial formulations and manufacturing procedures. Separate lots of raw materials for each replication were procured from a local supplier (UW Provision, Middleton, WI). Each treatment included varying amounts of salt, water, and either SS (30SS, 50SS/KCl) or NFE (30NFE, 50NFE/KCl) with water adjustments made to compensate for the water contribution from SS and NFE. These prescribed salt and water concentrations for each treatment and for all product types investigated are outlined in Table 1.

Bacon. Bacon was manufactured by randomly assigning 10 fresh pork bellies to 1 of 4 treatments resulting in 2 bellies per TRT and C. All treatments in this study included, on a total formulation basis, 0.6% sugar, 0.4% sodium tripolyphosphate, and the treatment specified salt (flake 99.8% NaCl or KCl), water, SS (30SS, 30SS/KCl) or NFE (30NFE, 30NFE/KCl; Table 1), in addition to 547 mg/kg sodium erythorbate and 120 mg/kg sodium nitrite, added on a meat block basis.

The individual treatment brine solutions were manufactured by first dissolving the sodium tripolyphosphate in cold water, followed by salt (flake or KCl), sugar, sodium erythorbate, sodium nitrite, and either SS or NFE. Bellies were injected in a random order using a multi-needle injector (Fomaco Model FGM 20/20S, Food Machinery Company A/S, Copenhagen, Denmark) to 12% over non-injected weight. Each belly was weighed prior to injection and after injection to record brine pick-up. After a 12 h hold under refrigeration (4°C), all TRT were thermal processed in a single truck oven (Alkar Model 450 MiniSmoker, Alkar Engineering Corp., Lodi, WI) using a common bacon thermal processing schedule consisting of an 8-h dry bulb/wet bulb ramping cook schedule beginning at 40.0°C and ending at 51.6°C until a final internal temperature of 53.9°C was reached. After thermal processing was complete, the bacon slabs were immediately chilled until the internal temperature was below 4.4°C. Before slicing, bacon slabs were tempered for 2 h at –20°C, sliced 2.5-mm thick with an automatic slicer (Bizerba A400FB, Bizerba GmbH & Co., Balingen, Germany), vacuum packaged (Ultravac 2100-C Vacuum Packager, Koch Equipment, Kansas City, MO) in vacuum pouches (3 mil high barrier EVOH pouches, Deli 1 material; oxygen transmission rate, 2.3 cm^3/cm^2; 24 h at 23°C; water transmission rate, 7.8 g/m^2; 24 h at 37.8°C; and 90% relative humidity; WinPak, Winnipeg, Manitoba, Canada), and stored at 4°C until sampling.

Beef jerky. Ready-to-eat, ground-and-formed beef jerky was manufactured utilizing beef cap-off inside rounds *(semimembranosus)* obtained from a local supplier and trimmed free of all exterior fat and connective tissue. The trimmed rounds were coarse ground through a grinder (Biro Model 6642, Biro Manufacturing Company, Marblehead, OH) using a 19.05-mm plate and were then re-ground through a 3.18-mm plate. The ground meat was then randomly separated into 5 batches of 6.80 kg each and randomly assigned to the treatments. All beef jerky treatments included, on a total formulation basis, 84.22% beef inside rounds, 0.54% seasoning (ground black pepper, allspice, and garlic), and the treatment specified salt (flake or KCl), water, SS (30SS, 50SS/KCl), or NFE (30NFE, 50NFE/KCl; Table 1) in addition to 547 mg/kg sodium erythorbate and 156 mg/kg sodium nitrite, added on a meat block basis.

To generate the beef jerky treatments, finely ground beef obtained from a local supplier was first mixed with salt (flake, KCl, or SS/NFE source) and sodium nitrite for 2 min in a double action paddle mixer (Leland Model 100DA, Leland Detroit Manufacturing Company, Detroit, MI) followed by mixing all spices, sodium erythorbate, water for an additional 3 min. The mixture was then transferred to a rotary-vane vacuum filler (Handtmann VF 608 Plus vacuum filler, Handtmann CNC Technologies Inc., Buffalo Grove, IL) and formed into strips using an extruder (Colosimo Model 200 sausage/jerky press, Colosimo's Original Sausage, Magna UT) attachment with a 3 slot die (0.95 cm × 3.175 cm). Strips of beef jerky were then placed on smokehouse rack screens with the screen location randomly selected for each replication and thermal processed in a single truck smokehouse using a standard beef jerky smokehouse schedule consisting of a 3 h (< 50% relative humidity) wet bulb/dry bulb ramping thermal processing schedule starting at 53.8°C and ending at 76.6°C until an internal temperature of 71.2°C was achieved. The cook process was immediately followed by drying at 76.6°C with 0% relative humidity until a water activity of 0.86 was reached in all treatments. After cooking and drying, the beef jerky was cut into 15.24-cm-long strips, vacuum packaged, and stored at 4°C until testing.

Boneless ham. Ready-to-eat boneless, deli-style ham was manufactured with pork ham inside muscles (*semimembranosus*) obtained from a local supplier, trimmed of all exterior fat and connective tissue and the cap (*gracillus*) removed. The trimmed inside ham muscles were ground through a kidney plate and were separated into 5 batches of 9.07 kg and randomly assigned to all treatments. All ham treatments C included, on a total formulation basis, 83.33% pork inside ham muscles, 1.38% sugar, 0.33% sodium tripolyphosphate, and the treatment specified salt (flake or KCl), water, SS (30SS, 30SS/KCl) or NFE (30NFE, 30NFE/KCl; Table 1) in addition to 547 mg/kg sodium erythorbate and 200 mg/kg sodium nitrite, added on a meat block basis.

The individual treatment brine solutions were manufactured by first dissolving sodium tripolyphosphate in cold water, followed by the salt (flake or KCl), sugar, sodium erythorbate, sodium nitrite, and SS or NFE (as prescribed by treatments). Boneless ham was produced by tumbling (Lyco Model LT-40, Lyco Sales Ltd., Janesville, WI) coarse ground pork muscles with a randomly selected brine solution containing all non-meat ingredients under vacuum for 1 h at 18 rpm. After tumbling, the product was held for 12 h for cured-color development at 4°C. The stuffing order was randomly determined and each ham mixture transferred to a rotary-vane vacuum filler and stuffed into 6.66-cm (diameter) fibrous casings (Vista International Packaging, Kenosha, WI) forming individual chubs (2.27 kg). Boneless ham treatments were hung on a smokehouse truck at randomized locations and processed in the single truck smokehouse using a 5 step ramp-up steam cook process (100% relative humidity) starting at 60cC and finishing at 82.2°C (100% RH), with no external smoke application, to an internal temperature of 71.2°C. After cooking, the hams were cooled to less than 4.4°C, sliced to 3.2 mm thick on a manual deli slicer, vacuum packaged, and stored at 4°C until later sampling.

Summer sausage. Ready-to-eat summer sausage was manufactured with USDA Choice ground (3.2 mm) beef chuck (80% lean/20% fat) obtained from a local supplier, separated into 5 batches of 9.07 kg, and randomly assigned to the treatments. All treatments included, on a total formulation basis, 82.68% lean ground beef, 1.08% seasoning mix (coriander, black pepper, ground mustard, mustard seed, garlic powder, nutmeg, and allspice), 0.62% dextrose, 0.03% lactic acid starter culture (Saga 200, *Pediococcus* spp., Kerry Ingredients, Beloit, WI), and the TRT or C specified salt (flake or KCl), water, SS (TRTs 30SS, 50SS/NFE) or NFE (30NFE, 50NFE/KCl; Table 1) in addition to 547 mg/kg sodium erythorbate and 156 mg/kg sodium nitrite, added on a meat block basis.

Ground beef (80% lean/20% fat), salt (flake, KCl, or SS/NFE source), and sodium nitrite were mixed in a double action paddle mixer for 2 min. Dextrose and spices were then added and mixed an additional 2 min followed by the lactic acid starter culture addition and 1 additional min of mixing. The mixture was then transferred to a rotary-vane vacuum filler stuffed into 6.35-cm (diameter) fibrous casings (Vista International Packaging, Kenosha, WI) to a weight of 2.27 kg per chub. Thermal processing took place in a single truck smokehouse using a standard summer sausage smokehouse schedule fermenting to an internal pH of 4.8 at 40°C followed by cooking to an internal temperature of 71.2°C with a dry bulb/wet bulb ramp-up cook schedule starting at 54.4°C and ending at 76.6°C. After cooking, the summer sausage was placed in a 4°C cooler until the temperature was reduced to less than 4.4°C, sliced to 4.0 mm thickness on a manual deli slicer, vacuum packaged, and stored at 4°C until sampling.

Water activity

Water activity (a_w) was measured on all beef jerky samples using an Aqua Lab water activity meter (AquaLab Model CX2, Decagon Devices Inc., Pullman, WA) to confirm the aw met the industry standard of no more than 0.86 used for food safety. For measurement of aw, strips of beef jerky were periodically removed from the smokehouse near the completion of drying to monitor aw status. Samples were allowed to cool to room temperature, were finely chopped, inserted into manufacturer provided sampling cups, and placed into the machine for determination. The water activity machine was calibrated with water activity standards of 1.000 and 0.760 prior to analyzing samples. Measurements of water activity were conducted in triplicate.

Instrumental color measurements

Instrumental color was measured using a Minolta Colorimeter (Model CR-300, Minolta Camera Co., Ltd., Osaka, Japan; 1 cm aperture, illuminant D65, and 2° observer angle). The colorimeter was standardized using the same packaging material that was used on the samples, placed over the white standardization tile. Values for the white standard tile were L^* = 97.06, a* = –0.14, b* = 1.93 (Y = 93.7, x = 0.3163, and y = 0.3324). Commission Internationale de l'Eclairage (CIE) L*(lightness), a*(redness), and b*(yellowness) external and internal color measurements were taken at 2 wk post manufacture for each product (American Meat Science Association, 2012).

Color analysis for boneless ham and summer sausage consisted of taking 3.00-cm thick sections and cutting them lengthwise and placing them in a vacuum package. External and internal measurements were immediately taken at 2 randomly selected locations on all samples. After placing in a vacuum package, bacon sample measurements were conducted on lean and fat portions of the slices and both the lean and fat external sides of the bacon slab. Beef jerky strips were sliced lengthwise to expose the internal surface for color measurement and placed in a vacuum package.

ph measurements

The pH levels were measured using methods described by Sebranek et al. (2001). Samples were blended in a 1:9 ratio of sample to distilled, deionized water (DDW) and homogenized with a Polytron Mixer (P10–35GTT, Dispersing Aggregate PTA-20/2W, Kinematica, AG, Lucerne, Switerzland) at setting 7 for 45 s. Whatman #1 filter paper was folded and pushed into the 150 mL beaker slurry to allow the fat free solution to come through the paper. The tip of the electrode was placed into the solution and pH was measured with a pH meter (Accumet Basic AB15 Plus pH Meter, Fisher Scientific, Fair Lawn, NJ.) equipped with an electrode

(Accument combination pH electrode with Ag/AgCl reference Model 13–620–285, Fisher Scientific, Fair Lawn, NJ) calibrated with 4.00 and 7.00 phosphate buffers. Measurements were made in triplicate for each treatment.

Purge level measurements

Purge levels were measured after 14 d of refrigerated 4°C storage. This time point was selected as it coincided with sensory evaluations. Three packages from each treatment were weighed, drained, and then reweighed.

Cook yield measurements

Cook yields were determined for the products by taking a raw weight on each individual treatment batch prior to thermal processing and reweighing after completion of thermal processing and cooling.

NaCl level determination

NaCl levels were measured using methods described by Sebranek et al. (2001). Samples were finely ground with a food processor (Fresh Chop Model 72600, Hamilton Beach Brands Inc., Southern Pines, NC) and blended in a 1:9 ratio of sample to DDW. Samples were then heated on a hot plate set at 300°C until a rolling boil was reached. Samples were removed from the heat source and allowed to cool to ambient temperature. After cooling, a piece of folded Whatman #1 filter paper was pushed into the 150 mL beaker and a Quantab strip (Quantab Titrators for Chloride, High Range Titrators–300–6,000 mg/kg Cl, Hach Company, Loveland, CO) was inserted into the solution and allowed to go to completion. Percent NaCl was determined by using the conversion chart provided on the Quantab bottle. All values were multiplied by 10 to account for the dilution factor to give the actual percentage of salt. Measurements were performed in duplicate for each treatment. Extrapolation of treatment NaCl concentration containing KCl was performed by calculating the ingoing sodium chloride content for each control's formulation flake salt in the product formulation and reported with a 50% reduction.

Instrumental texture measurements

Texture profile analysis (TPA) was conducted on all product types based on methods described by American Meat Science Associtation (2016) and Wenther (2003) using an HDi Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The texture analyzer was equipped with a 25-mm (diameter) cylinder (TA-25), which was utilized in a 2-compression test for summer sausage and boneless ham. A compression plate surface was utilized for beef jerky texture profile analysis based on methods described by Thiagarajan (2008). Bacon texture analysis utilized the star probe puncture analysis test described by Wenther (2003). The HD*i* Texture Analyzer was equipped with a 50 kg load cell and was calibrated using a 10 kg weight for all products tested. TPA was conducted immediately after removing TRT or C from a 2.2°C cooler and all tests were performed at 1.7 mm/s for both a 2-cycle 50% compression and 2-cycle 72% compression.

For boneless ham and summer sausage, TPA was conducted using 2 randomly selected product pieces from which 4 cores (15 mm diameter, 20 mm high) were removed providing 8 texture samples. For beef jerky, TPA was conducted on 8 randomly selected strips. Puncture analysis was also conducted on bacon treatments according to methods described previously (Wenther, 2003). Star probe texture analysis was conducted on the fat and lean sides of an approximately 4-cm long section removed from the blade end of each belly to determine fat and lean firmness. A TA-HD*i* Texture Analyzer, equipped with a 50 kg load cell and a 2-mm diameter puncture probe, was programmed to penetrate a distance equal to 40% of the sample height into the sample after detecting the surface at 50 g of resistance. The puncture penetration rate was 1.7 mm/s. For each treatment, 8 measurements were collected per sample and 2 samples were measured, resulting in 16 measurements per treatment.

Consumer sensory analysis

Samples for all meat product types investigated in this study were presented to consumer sensory panelists at the University of Wisconsin-Madison Sensory Analysis Laboratory (Madison, WI) 14 d post-manufacture following guidelines developed by American Meat Science Association (2016). Bacon was prepared by cooking slices in a 191°C convection oven (Hobart combi oven model 120, Hobart Corporation) for 13 min. After cooking, bacon slices were cut in half (midsection) and held in a warming cabinet (Flav-R-Fresh Impulse Display Cabinet, Hatco Corp., Milwaukee, WI) for no longer than 1 h while serving was conducted. Beef jerky samples were sliced into 7.6-cm strips and stored at 4°C until served to each panelist. Boneless ham and summer sausage were stored presliced at 4°C until serving to each panelist

Samples for sensory analysis were coded with a random 3-digit number and presented to consumers in a randomized monadic order. Panelists evaluated no more than 3 samples at a sitting and were provided water and unsalted crackers to cleanse their palates between samples. Sensory tests were conducted in individual booths under incandescent lighting of ~700 lx. Consumer sensory studies were conducted for each replication until 96 responses per treatment were achieved, resulting in a total of 288 responses per treatment. Panelists were asked to rate the samples for overall liking, appearance, texture, aroma, flavor, saltiness, and bitterness. Demographic questions were asked regarding ethnicity, age, gender, and consumption habits (Table 2). An additional question addressing cooking methods and doneness preference was added for the bacon sensory analysis. Responses for consumer sensory were collected using sensory software (FIZZ version 2.47B, Biosystemes, Couternon, France).

The sensory analysis for summer sausage was broken into 2 complete blocks by SS or NFE treatments. Block 1 consisted of each panelist evaluating the 100FS and both SS treatments (30SS, 50SS/KCl). Block 2 consisted of each panelist evaluating the 100FS and both NFE treatments (30NFE, 50NFE/KCl). A minimum of 96 responses per treatment per replication were collected. Due to the blocking method implemented for summer sausage, resulting in more total panelists and 100FS samples needed to yield the targeted 96 responses for each treatment, a balanced incomplete block design (American Meat Science Association, 2016) was instead used for the 3 remaining products. This approach reduced the number of panelist 100FS responses while still yielding the target 96 responses for each treatment (for each replication).

The experimental design for the all other experiments (including bacon, beef jerky, and boneless ham sensory) consisted of a randomized complete block using a mixed effects model. Statistical analysis was performed for all measurements using computer software (JMP Pro version 10.0, SAS Inst. Inc., Cary, NC) under the MIXED model procedure. The model included the fixed main effects of the treatment (100FS, 30SS, 50SS/KCl, 30NFE, 50NFE/KCl) and replication ($n = 3$) resulting in 15 observations. The random effect was the interaction of treatment × replication. All least significant differences were found using the Tukey-Kramer pairwise comparison method with significance determined at $P < 0.05$.

Table 2. Demographic question responses for consumer sensory analysis of bacon, beef jerky, boneless ham, and summer sausage containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

Question	Bacon, %	Beef jerky, %	Boneless ham, %	Summer sausage, %
Gender (male):	52	53	54	65
Gender (female):	48	47	46	35
Age (years):				
< 18	1	1	2	8
18–34	45	34	29	60
25–35	39	36	35	14
35–44	4	10	9	4
45–54	5	10	12	12
55–64	5	8	11	1
65+	1	1	2	1
Ethnicity:				
African American	2	1	1	3
Asian	12	8	7	3
Caucasian	77	77	79	83
Hispanic	6	6	6	7
Native American/Pacific Islander:	1	1	1	1
Declined to answer	2	7	6	3
Consumption:				
Never eat	1	10	1	3
A few times per year	21	61	29	54
A few times per month	54	21	38	35
Once per week	20	5	19	3
More than once per week	4	3	13	5

Results and Discussion

Bacon

Instrumental color measurements. Both external and internal color measurements were conducted for the lean and fat portions on the bacon slabs with the least squares means displayed in Table 3. External lean color values for CIE L^*, a^*, and b^* ranged from 32.2 to 37.2, 14.7 to 17.0, and 15.2 to 18.1, respectively (data not shown) but were not affected ($P > 0.05$) by the addition of SS, NFE, or KCl. Internal lean color values for CIE L^* and a^* ranged from 48.4 to 53.3 and 9.4 to 11.7, respectively (data not shown) and were also not found significant while b^* values were significantly higher for all SS and NFE treatments compared to 100FS. These results indicate the use of SS and NFE contributed a yellowish appearance to the lean portion of the bacon slice.

External fat color measurements for CIE L^* and a^* were also affected by the addition of SS and NFE. Unlike external fat b^* where values ranged from 27.7 to 29.2 (data not shown) and showed no significant effects ($P > 0.05$), external fat L^* values were found significantly lower for 30SS, 50SS/KCl, and 30NFE as compared to 100FS while external fat a^* values were significantly higher for all SS and NFE treatments as compared to 100FS. This suggests an increase in the

Table 3. Least squares means for instrumental external and internal color, pH, purge, cook yield, salt, and texture analysis of bacon containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Lean	Fat						Cook		Lean peak		
	Internal[2]	External[2]		Internal[2]			Purge,	yield,	NaCl,	force,	Hardness,	Chewiness
Teatment[1]	b*	L*	a*	L*	b*	pH[3]	%[4]	%[5]	%[6]	N[7]	N[8]	(N × mm)[9]
100FS	6.5[c]	67.6[a]	9.70[b]	78.5[a]	12.8[b]	6.13[c]	0.86[b]	83.0[ab]	2.26[a]	8.11[b]	54.7[b]	210.0[a]
30SS	14.4[a]	63.0[b]	12.33[a]	76.1[ab]	17.6[a]	6.30[ab]	1.20[a]	79.0[b]	1.78[b]	6.35[c]	46.7[c]	167.9[b]
50SS/KCl	14.0[a]	62.4[b]	11.71[a]	75.6[b]	17.7[a]	6.16[bc]	0.81[b]	85.6[b]	1.13*	8.98[a]	62.7[a]	229.3[a]
30NFE	12.4[ab]	62.7[b]	11.49[a]	75.4[b]	17.9[a]	6.33[a]	1.29[a]	77.5[b]	1.85[b]	5.47[d]	56.7[c]	163.9[b]
50NFE/KCl	11.8[ab]	63.8[ab]	11.65[a]	75.4[b]	17.4[a]	6.37[a]	0.82[b]	87.2[a]	1.13*	7.23[b]	57.5[ab]	205.9[ab]
SEM[10]	0.45	0.49	0.18	0.31	0.35	0.03	0.06	1.10	0.05	0.29	1.02	6.97

[a–d]Means within same column with different superscripts are different ($P < 0.05$).

*Calculated NaCl mean from the C as Quantab method (measuring chloride ion content) could not result in accurate NaCl concentration due to KCl TRT inclusion.

[1]Treatments: 100FS = no sodium reduction (1.6% NaCl from flake salt); TRT 1 = 30% sodium reduction (all flake salt replaced with SS); 30SS = 50% sodium reduction (all flake salt replaced with SS + KCl); 30NFE = 30% sodium reduction (all flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (all flake salt replaced with NFE + KCl).

[2]Commission Internationale de l'Eclairage (CIE) *L* a* b**, where *L** = lightness or darkness on a 0 (black) to 100 (white) scale, *a** = redness (positive value) or greenness (negative value), or *b** = yellowness (positive value) or blueness (negative value).

[3]pH of bacon after thermal processing.

[4]Percentage of purge in bacon product package after 14 d storage at 4°C.

[5]Percentage cook yield = [(raw weight of bacon/cooked weight of bacon) × 100].

[6]Percentage of NaCl in bacon.

[7]Peak Force = Maximum force during puncture of sample.

[8]Hardness = The peak force during the first compression.

[9]Chewiness = The product of (hardness × cohesiveness × springiness).

[10]SEM = Standard error of the means.

reddish appearance of the external bacon fat with the inclusion of SS and NFE. Regarding internal color, *a** fat values ranged from 5.7 to 6.8 (data not shown) and yielded no significant differences among any TRT or C. Further, internal *L** fat values were lower ($P < 0.05$) for 50SS/KCl, 30NFE, and 50NFE/KCl compared to 100FS while internal *b** values were observed higher ($P < 0.05$) than the 100FS for all SS and NFE treatments indicative that the addition of SS and NFE may increase the yellowish appearance of the fat in bacon slices. Overall, the use of SS and NFE, regardless of the addition level, was found they could affect both internal and external fat and lean color; however, external color impacts may be partially negated due to the external color changes occurring from the application of smoke during thermal processing which may dilute or mask some of the actual SS or NFE treatment-induced color differences.

pH and NaCl measurements. The least squares means for pH measurements are displayed in Table 3. The pH levels of 30SS, 30NFE, and 50NFE/KCl were significantly higher than 100FS. The increase in meat system pH was not expected with the addition of SS and NFE since both SS and NFE have a pH of 4.59 and 5.26, respectively, which was expected to instead provide a meat system pH reduction. This phenomenon is likely explained by pH variation in the raw bellies used for the study.

NaCl concentrations were lower ($P < 0.05$) in 30SS and 30NFE as compared to the 100FS (Table 3). Statistical analysis was not performed on 50SS/KCl or 50NFE/KCl treatments as these were extrapolated values. Extrapolation was performed for this and all other products because the Quantab test strips used measured the presence of chloride ions (Cl^-) and were unable to distinguish between Cl^- from NaCl and Cl^- from KCl. Therefore, any measurements would have been inaccurate for NaCl content. Interestingly, NaCl levels in 30SS and 30NFE revealed levels less than the targeted 30% reduction (1.56% target; 1.78 and 1.85% actual). Reasons for not achieving the target reduction levels could be due to non-uniform injection rates throughout the belly and the sampling induced variation among the bacon.

Purge and cook yield measurements. The values for purge levels and cook yield measurements are shown in Table 3. Purge levels at 14 d of refrigerated storage (4°C) were higher ($P < 0.05$) for 30SS and 30NFE as compared to 100FS. It was not unexpected to observe purge loss for these treatments since reducing the NaCl content in 30SS and 30NFE by 30% compared to the

100FS would affect meat system ionic strength and related protein-water binding (Aberle et al., 2001; Frye et al., 1986). Interestingly, when KCl was included in formulations (50SS/KCl and 50NFE/KCl), no significant changes in purge loss were observed suggesting the chloride ion contributions from the KCl were highly effective for ionic strength and related water binding. Cook yields, although not showing any significant differences as compared to 100FS, displayed similar trends as for purge measurements. Differences in SS and NFE may play a role in ionic strength of the product, but the true extent is not fully understood.

Instrumental texture measurements. Both TPA and puncture measurements were conducted for bacon and results are reported on Table 3. TPA evaluation offered no significant differences among any SS or NFE treatments compared to 100FS for cohesiveness and springiness with values ranging from 58.1 to 61.0 and 5.9 to 6.5 respectively (data not shown). Significant decreases in hardness and chewiness were, however, observed for 30SS, 50SS/KCl and 30NFE (hardness), and 30SS and 30 NFE (chewiness) when compared to all other treatments. These results were expected as the reduction in sodium in these treatments would likely impact the gel strength of the meat system thus contributing to textural changes (Aberle et al., 2001; Frye et al., 1986). Lean peak force revealed significant differences between 30SS and 30NFE as compared to all other treatments. The differences can also be attributed to the reduction in sodium in these treatments impacting the amount of force required to puncture the product (Frye et al., 1986). Finally, no differences were noted for the lean total energy, fat peak force, and fat total energy ($P > 0.05$), with values ranging from 8.5 to 9.0, 1.2 to 1.4, and 2.3 to 2.8 respectively (data not shown).

Consumer sensory analysis. Results from consumer sensory tests are presented in Table 4. The 100FS, 30SS, and 50SS/KCltreatments received higher overall liking scores ($P < 0.05$) than 50NFE/KCl while 30SS, 30NFE, and 50SS/KCl treatments were not found different ($P > 0.05$) from 100FS. The appearance of cooked bacon was not found significantly different for any SS or NFE treatment compared to 100FS. This could be attributed to the maillard browning occurring from the cooking of the bacon slices which may have masked any change in color appearance caused by SS or NFE inclusion. The sensory response for texture was only found to be lower ($P < 0.05$) in 50NFE/KCl compared to 100FS. Aroma and flavor liking only decreased significantly in 30NFE and 50NFE/KCl as compared to 100FS suggesting SS maintained desirable bacon aromas and flavors. The saltiness liking was only found lower ($P < 0.05$) in 50NFE/KLl compared to 100FS while no significant differences were observed for any other SS or NFE treatment as compared to 100FS. These results support SS and NFE can successfully be used to maintain saltiness liking in all, except 50% reduction with NFE + KCl, sodium reduction systems investigated. Higher bitterness perception responses were reported ($P < 0.05$) for 50SS/KCl, 30NFE, and 50NFE/KCl treatments as compared to 100FS however no significant changes were observed for 30SS. This suggests that SS plays a better role in masking the effects of using KCL than NFE likely due to aroma and flavor contributions.

Table 4. Least squares means for consumer sensory analysis[1] of bacon containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Treatments[2]					
Attributes[1]	100FS	30SS	50SS/ KCl	30NFE	50NFE/ KCl	SEM[3]
Overall	6.94[a]	6.93[a]	6.84[a]	6.61[ab]	6.37[b]	0.043
Appearance	7.07[ab]	7.16[a]	6.87[ab]	6.83[ab]	6.76[b]	0.041
Texture	6.81[a]	6.53[ab]	6.61[ab]	6.62[ab]	6.23[b]	0.048
Aroma	6.97[a]	6.78[ab]	6.77[ab]	6.48[bc]	6.29[c]	0.041
Flavor	7.08[a]	6.87[ab]	6.78[ab]	6.57[b]	6.08[c]	0.047
Saltiness	6.24[a]	6.42[a]	6.32[a]	6.26[a]	5.53[b]	0.049
Bitterness[4]	0.723[a]	0.824[ab]	1.026[b]	0.993[bc]	1.164[c]	0.029

[a–c]Means within the same row with different superscripts are different ($P < 0.05$).

[1]Attributes with same superscript are based on a 9-point scale: 1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely.

[2]Treatments: 100FS = no sodium reduction (1.6% NaCl from flake salt); 30SS = 30% sodium reduction (all flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (all flake salt replaced with SS + KCl); 30NFE = 30% sodium reduction (all flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (all flake salt replaced with NFE + KCl).

[3]SEM = Standard error of the means.

[4]Bitterness attributes based on 6-point scale: 0 = no bitterness; 1 = very low bitterness; 2 = little bitterness; 3 = moderately bitter; 4 = very bitter; 5 = extremely bitter.

Beef jerky

Instrumental color measurements. Internal and external color measurements performed on beef jerky slices and the least squares means are reported in Table 5. External color values for CIE L^* values ranged from 26.5 to 27.8 (data not shown) and showed no significant changes from the addition of SS or NFE. External a^* and b^* values were lower ($P < 0.05$) for all SS and NFE treatments compared to 100FS indicating both redness and yellowness levels decreased in products containing SS and NFE. External a^* and b^*values showed an interest-

Table 5. Least squares means for instrumental external and internal color, texture profile analysis and salt measurements of beef jerky containing soy sauce (SS), fermented flavor enhancer (NFE) and sno SS/NFE (100FS)

	Color analysis[2]					Texture profile analysis			
	External		Internal						
Treatment[1]	a*	b*	L*	a*	b*	Hardness, N[3]	Cohesiveness, %[4]	Chewiness (N × mm)[5]	NaCl, %[6]
100FS	10.38^{a}	6.92^{a}	27.23^{a}	10.13^{a}	8.42^{b}	70.3^{a}	81.30^{a}	68.6^{a}	7.08^{a}
30SS	5.36^{c}	5.26^{b}	24.02^{b}	6.38^{c}	7.37^{c}	58.3^{i}	81.20^{a}	53.8^{b}	5.15^{b}
50SS/KCl	5.36^{c}	5.25^{b}	23.80^{b}	6.44^{c}	7.31^{c}	55.4^{b}	81.34^{a}	51.0^{b}	3.54*
30NFE	8.29^{b}	6.84^{a}	28.30^{a}	9.42^{b}	9.37^{a}	55.2^{b}	80.85^{b}	55.8^{b}	4.95^{b}
50NFE/KCl	8.32^{b}	6.82^{a}	27.87^{a}	9.52^{b}	9.47^{a}	53.3^{b}	80.62^{b}	54.1^{b}	3.54*
SEM[7]	0.210	0.09	0.241	0.173	0.103	1.194	0.166	1.255	0.274

[a–c]Means within the same column with different superscripts are different ($P < 0.05$).

*Calculated NaCl mean from the C as Quantab method (measuring chloride ion content) could not result in accurate NaCl concentration due to KCl TRT inclusion.

[1]Treatments: 100FS = no sodium reduction (3.0% NaCl from flake salt); 30SS = 30% sodium reduction (all flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (all flake salt replaced with SS + KCl); 30NFE = 30% sodium reduction (all flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (all flake salt replaced with NFE + KCl).

[2]Commission Internationale de l'Eclairage (CIE) *L*a*b**, where *L** = lightness or darkness on a 0 (black) to 100 (white) scale, *a** = redness (positive value) or greenness (negative value), or *b** = yellowness (positive value) or blueness (negative value).

[3]Hardness = The peak force during the first compression.

[4]Cohesiveness = The ratio of the positive force area during the second compression (50%) to that during the first compression (50%), calculated as [(Area 2/Area 1) × 100].

[5]Chewiness = The product of (hardness × cohesiveness × springiness).

[6]Percentage of NaCl in beef jerky.

[7]SEM = Standard error of the means.

ing trend where SS TRT (30SS and 50SS/KCl) were significantly lower ($P < 0.05$) than NFE TRT (30NFE and 50NFE/KCl) indicating the use of NFE did not decrease the redness nor yellowness to the same extent as SS did. The lighter appearance of the NFE product may partially explain this redness color phenomenon. However, just as for the bacon TRT, the addition of smoke may further offset any of the SS or NFE external color effects.

Internal CIE *L** color values were lower ($P < 0.05$) in both treatments containing SS compared to 100FS while both treatments containing NFE did not show any significant decrease ($P > 0.05$) in lightness compared to 100FS. Internal *a** values showed a similar trend to external *a** and *b** values as a decrease ($P < 0.05$) was observed in all SS and NFE treatments versus the 100FS. Further, the *a** values for both treatments containing SS were significantly lower than both treatments containing NFE. Compared to the 100FS, internal *b** values revealed an increase ($P < 0.05$) for 30NFE and 50NFE/KCl and a decrease ($P < 0.05$) for 30SS and 50SS/KCl. The results of the instrumental color analysis for beef jerky showed that while both SS and NFE contribute to color effects of redness and yellowness, the use of SS may have a larger impact on internal color values than NFE.

pH and NaCl measurements. No significant changes for pH levels were noted between among any treatments with ranges between 5.38 and 5.44 (data not shown). The least squares means for NaCl levels are displayed in Table 5.

Water activity and cook yield measurements. No significant differences existed between any treatments for both water activity and cook yield. Water activity ranged from 0.830 to 0.836 (data not shown) confirming shelf stable (per jerky regulatory requirements for water activity of < 0.85) and commercially typical treatments were produced. Cook yields ranged from 55.3 to 56.1% (data not shown). The low cook yields were expected as beef jerky is a dry product and no difference ($P > 0.05$) suggest that little variation existed as a result of cooking and drying.

Instrumental texture measurements. Textural profile analysis (TPA) was performed for all jerky treatments with results reported in Table 5. The TPA results revealed no differences ($P > 0.05$) for springiness and gumminess with ranges of 1.17 to 1.21 and 53.71 to 58.76, respectively (data not shown). Compared to the 100FS, decreases were observed for hardness and chewiness ($P < 0.05$) for all SS and NFE treatments. A lower hardness score could be attributed to a meat tenderizing effect SS and NFE may provide as illustrated in a study by Kim et al. (2013) where SS was added in a marination of *biceps femoris* and resulted in lower shear force values. Cohesiveness values were found lower ($P < 0.05$) for 30NFE and 50NFE/KCl compared to 30SS, 50SS/KCl and 100FS and may also possibly be explained by the tenderizing effects of NFE.

Consumer sensory analysis. Bacon cooking and degree of doneness preference demographic results revealed 78% of panelists preferred to fry bacon, 11% baked bacon, 10% microwaved bacon, 2% broiled their bacon and 1% cooked bacon using other means while 17% of panelists preferred bacon to be very crispy when cooked, 46% enjoyed their bacon crispy, 33% preferred their bacon somewhat crispy with some softness, and 5% of panelists preferred their bacon soft and not crispy.

The results of the consumer sensory tests are reported in Table 6. Overall liking was found lower ($P < 0.05$) for 30SS, 50SS/KCl, and 50NFE/KCl as compared to 100FSwhile 30NFE was not found different ($P > 0.05$) from 50SS/KCl or the 100FS. Compared to the 100FS, beef jerky appearance and texture responses were only found lower ($P < 0.05$) for 30SS and 50NFE/KCl while aroma was only lower ($P < 0.05$) for 30SS. Consumer sensory differences for flavor liking and bitterness intensity were not found to exist ($P > 0.05$) between any treatments. Finally, saltiness liking was found higher ($P < 0.05$) for 50SS/KCl compared to the 100FS and was numerically, although not statistically higher ($P > 0.05$) for 30NFE and 50NFE/KCl. The results from the consumer sensory testing revealed that all reduced sodium beef jerky treatments containing SS, NFE, and KCl were found acceptable for saltiness and flavor with low bitterness intensity despite the inclusion of the ingredients in the product treatments. Further, these results suggest the use of SS and NFE may have the ability to mask inherent bitterness associated with the use of KCl in high level sodium reduction treatments.

Table 6. Least squares means for consumer sensory analysis for beef jerky containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Treatments[2]					
Attributes[1]	100FS	30SS	50SS/KCl	30NFE	50NFE/KCl	SEM[3]
Overall	6.44[a]	5.86[c]	6.01[bc]	6.30[ab]	5.84[c]	0.047
Appearance	6.47[a]	6.09[bc]	6.32[abc]	6.39[ab]	6.01[c]	0.041
Texture	6.06[ab]	5.46[c]	5.65[bc]	6.11[a]	5.38[c]	0.054
Aroma	6.38[a]	6.05[b]	6.36[a]	6.32[ab]	6.17[ab]	0.036
Flavor	6.49[a]	6.25[a]	6.59[a]	6.51[a]	6.32[a]	0.043
Saltiness	5.56[b]	5.53[b]	5.97[a]	5.79[ab]	5.84[ab]	0.047
Bitterness[4]	1.02[a]	1.24[a]	1.06[a]	1.09[a]	1.18[a]	0.033

[a–c]Means within the same row with different superscripts are different ($P < 0.05$).

[1]Attributes with same superscript are based on a 9-point scale: 1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely.

[2]Treatments: 100FS = no sodium reduction (3.0% NaCl from flake salt); 30SS = 30% sodium reduction (all flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (all flake salt replaced with SS + KCl); 30NFE = 30% sodium reduction (all flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (all flake salt replaced with NFE + KCl).

[3]SEM = Standard error of the means.

[4]Bitterness attributes based on 6-point scale: 0 = no bitterness; 1 = very low bitterness; 2 = little bitterness; 3 = moderately bitter; 4 = very bitter; 5 = extremely bitter.

Boneless ham

Instrumental color measurements. External and internal color measurements CIE L^*, a^*, and b^* were conducted for boneless ham and the results are displayed in Table 7. External L^* values ranged from 69.58 to 69.79 (data not shown) with no significant changes as a result of adding SS or NFE. Compared to the 100FS, treatments containing NFE were found to reduce ($P < 0.05$) external a^* color values while no differences ($P > 0.05$) were noted for the SS containing treatments, suggesting that NFE may have more of an effect on external color

Table 7. Least squares means for instrumental external and internal color, purge and salt of boneless ham containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Color analysis[2]				
	External		Internal		
Treatments[1]	a*	b*	b*	Purge, %[3]	NaCl, %[4]
100FS	8.05[a]	5.22[b]	4.99[b]	0.852[b]	2.533[a]
30SS	7.95[a]	9.30[a]	8.99[a]	1.156[a]	1.762[b]
50SS/KCl	8.08[a]	9.24[a]	8.96[a]	0.876[b]	1.274*
30NFE	7.45[b]	9.21[a]	9.00[a]	1.162[a]	1.816[b]
50NFE/KCl	7.44[b]	9.25[a]	8.92[a]	0.866[b]	1.272*
SEM[5]	0.04	0.17	0.17	0.01	0.02

[a,b]Means within the same column with different superscripts are different ($P < 0.05$).

*Calculated NaCl mean from the C as Quantab method (measuring chloride ion content) could not result in accurate NaCl concentration due to KCl TRT inclusion.

[1]Treatments: 100FS = no sodium reduction (2.25% NaCl from flake salt); 30SS = 30% sodium reduction (25% of flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (25% of flake salt replaced with SS + 50% of flake salt replaced with KCl); 30NFE = 30% sodium reduction (50% of flake salt replaced with NFE); 50NFE/KCl4 = 50% sodium reduction (50% of flake salt replaced with NFE + 50% of flake salt replaced with KCl).

[2]Commission Internationale de l'Eclairage (CIE) $L^*a^*b^*$, where L^* = lightness or darkness on a 0 (black) to 100 (white) scale, a^* = redness (positive value) or greenness (negative value), or b^* = yellowness (positive value) or blueness (negative value).

[3]Percentage of purge in bones ham product package after 14 d storage at 4°C.

[4]Percentage of NaCl in boneless ham.

[5]SEM = Standard error of the means.

than SS. External b^* were found to be significantly higher for all SS and NFE treatments as compared to 100FS suggesting an increase in yellow hue was observed in all treatments that contained SS and NFE. Just as for the previous products discussed, any external color impacts from SS and NFE can likely be negated by the application of smoke during thermal processing.

Internal color values for CIE L^* and a^* values ranged from 67.16 to 67.46 and 8.56 to 8.65 respectively (data not shown), and showed no significant changes of any treatment containing SS and NFE when compared to 100FS. Internal b^* values revealed significantly higher color values for all SS and NFE treatments compared to 100FS, suggesting there is a visually apparent increase in yellowness of internal ham surface with any addition level of SS and NFE. These results confirm that SS and NFE have an impact on color of boneless ham regardless of addition levels and may be explained by the lighter pigmentation present from a lower concentration of myoglobin in this product compared to the others investigated in this study.

pH and NaCl measurements. The pH measurements for the boneless ham treatments showed no significant differences among any of the treatments with pH levels ranging from 6.16 to 6.29 (data not shown). These results were expected and confirm SS and NFE inclusion did not affect the overall pH of the boneless ham treatments. In addition, NaCl concentration were found lower ($P < 0.05$) for 30SS and 30NFE as compared to 100FS (Table 7).

Purge and cook yield measurements. Boneless ham purge measurements at 14 d are presented in Table 7. The results revealed significantly higher purge loss for 30SS and 30NFE compared to 50SS/KCl, 50NFE/KCl, and 100FS. The higher purge losses for 30SS and 30NFE were expected because of the lower concentrations of chloride present from the NaCl-reduction only approach for these treatments. Since the ionic strength would have been reduced, the ability for water-holding-capacity was diminished. As observed with KCl-containing treatments, purge losses were not found different ($P > 0.05$) than the 100FS and can be explained by the chloride ion contribution from the KCl to the treatments. Cook yield values ranged from 92.4 to 94.9% and no significant differences were observed suggesting neither the NaCl reduced nor the KCl included treatments negatively or positively affected cook yields. These results further suggest that the sodium reduction treatments investigated in this study may provide acceptable processing attributes as salt-important thresholds for both purge loss and cook yields were approached as suggested by the significant and nonsignificant findings noted.

Instrumental texture measurements. No significance was observed for hardness, cohesiveness, springiness, and chewiness factors among any of the boneless ham treatments (data not shown). Data ranged from 52.41 to 56.53, 51.57 to 52.34, 5.93 to 6.01, and 170.90 to 174.18, respectively. These results were unexpected since reducing NaCl would also be expected to affect protein function and related textural properties. A study by Thiel et al. (1986) showed decreases in texture attributes in boneless ham with sodium reductions above 50% which is not consistent with our findings in this study. Possible explanations for the lack of differences may be due to impact from inherent variations of muscle fiber orientation or loss of muscle structure integrity from particle reduction existing among the different treatments and resulting from the boneless ham manufacture itself. Addition of KCl in 50% sodium reduction treatments may have mitigated the effects of the sodium reduction.

Consumer sensory analysis. Results from consumer sensory tests are reported in Table 8. Overall liking responses were found higher ($P < 0.05$) for the C compared to 50SS/KCl, 30NFE, and 50NFE/KCl. This is consistent with a study by Thiel et al. (1986) in

Table 8. Least squares means for consumer sensory analysis for boneless ham containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Treatments[2]					
Attributes[1]	100FS	30SS	50SS/KCl	39NFE	50NFE/KCl	SEM[3]
Overall	6.28^{a}	5.92^{ab}	5.88^{b}	5.83^{b}	5.77^{b}	0.043
Appearance	6.18^{a}	6.09^{a}	6.32^{a}	6.07^{a}	6.06^{a}	0.039
Texture	6.44^{a}	6.23^{ab}	6.19^{ab}	6.12^{ab}	5.97^{b}	0.042
Aroma	5.55^{a}	5.70^{a}	5.53^{a}	5.45^{a}	5.54^{a}	0.039
Flavor	6.25^{a}	5.92^{ab}	5.69^{bc}	5.87^{abc}	5.55^{c}	0.047
Saltiness	5.96^{a}	5.62^{ab}	5.58^{b}	5.74^{ab}	5.49^{b}	0.042
Bitterness[4]	0.56^{c}	0.70^{bc}	0.92^{ab}	0.96^{a}	1.16^{a}	0.030

[a–c]Means within the same row with different superscripts are different ($P < 0.05$).

[1]Attributes with same superscript are based on a 9-point scale: 1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely.

[2]Treatments: 100FS = no sodium reduction (2.25% NaCl from flake salt); 30SS = 30% sodium reduction (25% of flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (25% of flake salt replaced with SS + 50% of flake salt replaced with KCl); 30NFE = 30% sodium reduction (50% of flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (50% of flake salt replaced with NFE + 50% of flake salt replaced with KCl).

[3]SEM = Standard error of the means.

[4]Bitterness attributes based on 6-point scale: 0 = no bitterness; 1 = very low bitterness; 2 = little bitterness; 3 = moderately bitter; 4 = very bitter; 5 = extremely bitter.

which overall taste acceptability showed decreases in higher sodium reduction TRT of chunked and formed ham. No differences ($P > 0.05$) were noted by consumer panelists for appearance or aroma between any of the treatments indicating that treatments containing SS, NFE, and KCl had no impact on the consumer acceptability for these attributes. Texture responses were numerically lower for all SS and NFE treatments but only significantly lower for 50NFE/KCl compared to 100FS. This is consistent with a study performed by McGough (2011) which showed significant decreases in texture liking for frankfurters containing SS and NFE. For flavor liking, the 100FS was higher ($P < 0.05$) than 50SS/KCl and 50NFE/KCl while no differences existed ($P > 0.05$) between 30SS and 30NFE compared to the 100FS. These results suggest that treatments containing KCl may have imparted undesirable flavors since non-KCl containing SS and NFE treatments were not found different from the 100FS while those that did contain KCl were found different from the 100FS suggesting that SS and NFE testing levels did not mask the KCl flavor present in the product. Lower responses for saltiness were reported ($P < 0.05$) for 50SS/KCl and 40NFE/KCl compared to the 100FS; while, none of the NFE and SS treatments were found to be different ($P > 0.05$) from one another nor were 30SS and 30NFE different ($P > 0.05$) from the 100FS. These results were not unexpected since flake salt reductions existed in the KCl containing treatments compared to those without KCl as a result of meeting treatment sodium reduction targets (Table 1). Bitterness perception responses were higher ($P < 0.05$) for 50SS/KCl, 30NFE, and 40NFE/KCl compared to the 100FS. Although, it was not unexpected to see the bitterness perception findings in the treatments containing KCl, it was not anticipated to also see this perception for the non-containing KCl 30NFE. Reasons for this outcome are unclear but may be related to a similar group or groups of flavor compounds eliciting a bitterness consumer response which may have been amplified and subsequently detected by panelists due to the blander flavor profile of ham.

Summer sausage

Instrumental color measurements. External and internal color measurements CIE L^*, a^*, and b^* were conducted for summer sausage and the results are presented in Table 9. External L^* values showed no significant differences for any treatments and ranged from 48.47 to 48.56 (data not shown). For all SS and NFE treatments, external a^* values were found lower ($P < 0.05$) while internal b^* values were determined to be higher ($P < 0.05$) than the 100FS, indicating a

Table 9. Least squares means for instrumental external and internal color, texture profile analysis, cook yield and salt levels for summer sausage containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Color analysis[2]			Texture profile analysis			
	External		Internal				
Treatments[1]	a*	b*	a*	Hardness, N[3]	Chewiness (N × mm)[4]	Cook yield, %[5]	NaCl, %[6]
100FS	15.03[a]	11.46[b]	16.99[a]	39.3[a]	112.6[a]	83.07[a]	2.84[a]
30SS	14.41[b]	14.42[a]	15.99[b]	31.4[b]	87.3[b]	81.16[b]	1.86[b]
50SS/KCl	14.58[b]	14.32[a]	15.94[b]	31.6[b]	89.5[b]	82.89[a]	1.42*
30NFE	14.38[b]	14.33[a]	15.93[b]	26.0[c]	74.2[c]	81.46[b]	1.92[b]
50NFE/KCl	14.50[b]	14.25[a]	15.95[b]	26.0[c]	74.2[c]	82.97[a]	1.42*
SEM[7]	0.04	0.12	0.05	0.52	1.54	0.15	0.06

[a–c]Means within the same column with different superscripts are different ($P < 0.05$).

*Calculated NaCl mean from the C as Quantab method (measuring chloride ion content) could not result in accurate NaCl concentration due to KCl TRT inclusion.

[1]Treatments: 100FS = no sodium reduction (2.5% NaCl from flake salt); 30SS = 30% sodium reduction (50% of flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (50% of flake salt replaced with SS + 50% flake salt replaced with KCl); 30NFE = 30% sodium reduction (50% of flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (50% of C flake salt replaced with NFE + 50% C flake salt replaced with KCl).

[2]Commission Internationale de l'Eclairage (CIE) L^* a^* b^*, where L^* = lightness or darkness on a 0 (black) to 100 (white) scale, a^* = redness (positive value) or greenness (negative value), or b^* = yellowness (positive value) or blueness (negative value).

[3]Hardness = The peak force during the first compression.

[4]Chewiness = The product of (hardness × cohesiveness × springiness).

[5]Percentage cook yield = [(raw weight of summer sausage/cooked weight of summer sausage) × 100].

[6]Percentage of NaCl in summer sausage.

[7]SEM = Standard error of the means.

decrease in redness and an increase in yellowness existed as a result of adding, SS, NFE, and KCl.

Internal CIE L^* and b^* color values did not provide any significant effects and ranged from 40.0 to 40.2 and 16.3 to 16.4 respectively (data not shown). Internal a^* values followed a similar trend to external a^* and b^* values as the 100FS was higher ($P < 0.05$) for internal redness than all other SS and NFE treatments. These results suggest SS and NFE can impact the color of summer sausage when included in the formulation. Since the summer sausage tested was 100% beef and was highly pigmented due to the nature of the species and raw materials used, the reason for color differences may be explained by the dilution of color pigment from the addition of the lighter pigmented SS and NFE ingredients. In addition, the use of smoke during the thermal process may also mitigate the external color differences found with the SS and NFE containing treatments.

pH and NaCl measurements. No significant change in pH was observed for any treatments with pH values ranging from 4.5 to 4.6 (data not shown). A lower pH was expected due to the fermentation process employed for this product. As expected, NaCl concentrations were found lower for all SS and NFE treatments compared to the 100FS and were significantly lower for 30SS and 30NFE.

Purge and cook yield measurements. No significant differences were found between the SS or NFE treatments and 100FS for purge levels after 14 d of storage or cook yields with loss values ranging from 2.09 to 2.19% (data not shown). On the contrary, cook yields for 30SS and 30NFE were significantly lower ($P < 0.05$) than the 100FS and were also lower ($P < 0.05$) than 50SS/KCl and 50NFE/KCl. Because of the impact pH has on water holding capacity where protein functionality is decreased as the pH approaches the isoelectric point of meat (pH = 5.2), with the low meat system pH's of the treatments (4.5 to 4.65), it is likely the important salt (chloride) threshold impacting ionic strength and where protein functionality was not reached for 30SS and 30NFE but was attained from the addition of KCl in 50SS/KCl and 50NFE/KCl providing the results observed. As such, these results show that when removing NaCl from summer sausage without replacement of known chloride-containing salt substitutes, a decrease in cook yield may be expected.

Instrumental texture measurements. Texture profile analysis (TPA) was conducted for summer sausage with the least squares means presented on Table 9. Hardness and chewiness values were significantly lower for all SS and NFE treatments compared to the 100FS while 30SS and 50NFE/KCl were also found to have lower ($P < 0.05$) values than 30SS and 50NFE/KCl. Cohesiveness and springiness data ranged from 45.88 to 47.24 and 6.04 to 6.07 respectively (data not shown) but revealed no significant differences as a result of adding SS, NFE, or KCl to any treatment. These results show that decreases in hardness and chewiness may be attributed to the use of SS and NFE in summer sausage and is supported by research from Kim et al. (2013) who showed that when SS was added to a beef product, a decrease in the shear force resulted. These results could also be explained by the acidity of the SS (4.75) versus NFE (5.0) where acidification may have played a role in impacting the product texture. As such, TPA analysis indicates that SS and NFE may play a role in the textural properties of summer sausage although the exact reason is not well understood.

Consumer sensory analysis. Consumer sensory results are reported in Table 10. Results from each block (block 1 = 100FS, 30SS, 50SS/KCl; block 2 = 100FS, 30NFE, 50NFE/KCl) were analyzed separately. Block 1 and 2 100FS treatments received ($P < 0.05$) higher consumer responses for overall liking, appearance, texture, aroma, flavor, and saltiness liking but lower responses for bitterness than 30SS and 50SS/KCl or 30NFE and 50NFE/KCl, respectively. In addition, compared to 30SS and 30NFE, the respective KCl containing treatments received significantly lower responses for overall likeness and flavor while receiving higher ($P < 0.05$) scores for bitterness. Just as for the boneless ham, these results are not completely unexpected since it is known that salt has flavor enhancing properties (Weiss et al., 2010) and flake salt reductions did exist in the KCl containing treatments compared to those without KCl as a result of meeting treatment sodium reduction targets (Table 1). However, although flake salt reductions existed between 30SS and 50SS/KCl as well as between 30NFE and 50NFE/KCl, consumer saltiness scores were interestingly not found different ($P > 0.05$) suggesting other sensory attributes possibly caused by the fermentation process may be responsible for these findings.

Conclusions

All product types investigated in this study containing SS, NFE, and KCl as part of a sodium reduction system revealed, depending on product and treatment, both increases and decreases for all physiochemical and sensory attributes investigated. For consumer sensory, bacon, beef jerky, and boneless ham products were determined to be successful in minimizing decreases in saltiness liking responses at low level SS and NFE TRT. These findings are concluded

Table 10. Least squares means for sodium reduction experiments consumer sensory analysis of summer sausage containing soy sauce (SS), fermented flavor enhancer (NFE) and no SS/NFE (100FS)

	Block 1 treatments[1]				Block 2 treatments[2]			
Attributes	100FS	30SS	50SS/KCl	SEM[3]	100FS	30NFE	50NFE/KCl	SEM[3]
Overall[4]	6.84^{a}	6.11^{b}	5.75^{c}	0.060	6.90^{a}	5.91^{b}	5.53^{c}	0.061
Appearance[4]	6.72^{a}	6.43^{b}	6.38^{b}	0.048	6.73^{a}	6.39^{b}	6.34^{b}	0.046
Texture[4]	6.46^{a}	6.10^{b}	5.86^{b}	0.056	6.51^{a}	5.87^{b}	5.61^{b}	0.056
Aroma[4]	6.54^{a}	5.99^{b}	5.73^{b}	0.055	6.62^{a}	5.76^{b}	5.64^{b}	0.055
Flavor[4]	6.96^{a}	5.91^{b}	5.40^{c}	0.067	7.04^{a}	5.74^{b}	5.19^{c}	0.067
Saltiness[4]	6.38^{a}	5.87^{b}	5.63^{b}	0.055	6.43^{a}	5.73^{b}	5.43^{b}	0.055
Bitterness[5]	0.37^{a}	1.01^{b}	1.32^{a}	0.042	0.86^{c}	1.02^{b}	1.26^{a}	0.044

$^{a-c}$Means within the same row and block with different superscripts are different ($P < 0.05$).

[1]Treatments Block 1: 100FS = no sodium reduction (2.5% NaCl from flake salt); 30SS = 30% sodium reduction (50% of flake salt replaced with SS); 50SS/KCl = 50% sodium reduction (50% of flake salt replaced with SS + 50% of flake salt replaced with KCl).

[2]Treatments Block 2: 100FS = no sodium reduction (2.5% NaCl from flake salt); 30NFE = 30% sodium reduction (50% of flake salt replaced with NFE); 50NFE/KCl = 50% sodium reduction (50% of flake salt replaced with NFE + 50% offlake salt replaced with KCl).

[3]SEM = Standard error of the means.

[4]Attributes with same superscript are based on a 9-point scale: 1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely.

[5]Bitterness attributes based on 6-point scale: 0 = no bitterness; 1 = very low bitterness; 2 = little bitterness; 3 = moderately bitter; 4 = very bitter; 5 = extremely bitter.

to be due to the saltiness potentiating properties both SS and NFE possess. Yet, numeric and in some cases significant decreases for overall liking (and other sensory attributes) were observed in all products for some of the treatments; however, the true practical implication relative to product quality and consumer acceptability would need to be more closely assessed. Often, treatments containing SS scored better in consumer sensory testing and showed less ranges of differences across attributes versus comparable NFE results. Despite both differences and non-differences noted and discussed throughout this study; the greater value of this research is providing a better understanding the effects SS and NFE have, as part of sodium reduction systems, for different processed meat products with uniquely different demands for salt. Based on the results from the research conducted, it can be concluded that overall sodium reductions are feasible based on both physiochemical and sensory properties utilizing SS, NFE, and KCl. Lower levels of SS and NFE inclusion appeared to perform better; however, further research with higher levels of inclusion of these ingredients using KCl may show even greater improvements. However, care must be taken to understand how the results from this study correlate to other products beyond the scope of this study. The results from this study demonstrate the reduction of sodium can, in certain instances, have noticeable effects on product quality; however, that effect can be minimized to some degree through the use of SS and NFE or other meat processing technologies and/or ingredients not included in this study. The research has shown the feasibility of maintaining consumer acceptability while identifying and outlining some of the limitations of sodium reduction using SS and NFE.

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